

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

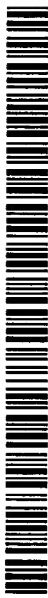


(43) International Publication Date
6 September 2002 (06.09.2002)

PCT

(10) International Publication Number
WO 02/067792 A2

- (51) International Patent Classification⁷: **A61B 17/70**
- (21) International Application Number: **PCT/US02/06134**
- (22) International Filing Date: **27 February 2002 (27.02.2002)**
- (25) Filing Language: **English**
- (26) Publication Language: **English**
- (30) Priority Data:
60/272,102 **28 February 2001 (28.02.2001)** **US**
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- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZM, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).
- Published:**
— *without international search report and to be republished upon receipt of that report*
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- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*



WO 02/067792 A2

(54) Title: **FLEXIBLE SPINE STABILIZATION SYSTEMS**

(57) Abstract: A spine stabilization system includes a flexible member attachable to a portion of the spinal column. The member includes components that are oriented and function similar to the natural fiber orientation of the anterior longitudinal ligament and annulus tissue. The use of components resist loading applied by extension and rotation of the spine, while the flexibility of the member does not subject it to the compressive loading of the spinal column segment to which it is attached.

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FLEXIBLE SPINE STABILIZATION SYSTEMS

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BACKGROUND

The present invention relates to orthopedic implants, and more particularly, to flexible spinal stabilization systems.

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Interbody fusion device, artificial discs, interbody spacers and other devices have been inserted in a spinal disc space or engaged to a vertebral body. For example, as shown in Fig. 1, a pair of interbody fusion devices I1 and I2 are inserted into an intradiscal space between the L5 and S1 levels of the spinal column. Aorta A1 and vena cava A2 along with other tissue and vasculature also extend along the anterior aspect of the spinal column. As shown in Fig. 2, the anterior longitudinal ligament AL extends along the anterior portion of the disc space. The disc space is surrounded by annulus fibrosus or annulus fibers AF. Insertion of implants I1 and I2 into the disc space can be facilitated by the removal of all or a portion of the anterior longitudinal ligament AL and the annulus fibers AF.

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In order to stabilize the spinal column, it is known to secure a rigid metal construct to each of the vertebral bodies on either side of the spinal disc space after inserting devices or performing surgical procedures in the disc space or on the vertebral bodies. For example, a rigid metal plate can be placed along the anterior aspect of the vertebrae and secured to the L5 and S1 levels after insertion of implants I1 and I2 into the disc space therebetween. In another example, a rigid rod or plate can be secured to the posterior portions of vertebrae V1 and V2 after anterior insertion of implants I1 and I2.

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While rigid metal constructs provide adequate load resistance, there can be drawbacks, such as the intrusion of the construct into the adjacent tissue and vasculature, stress shielding, multiple surgeries for installation, and fatigue. What are needed are systems that do not require posterior hardware to support the spinal column or rigid anterior, antero-lateral, or lateral plates and constructs. The systems should be resistant to fatigue, stress shielding and tensile and rotational loads that are typically applied to the spinal column. The present invention is directed toward meeting these needs, among others.

SUMMARY OF THE INVENTION

The present invention is directed to spine stabilization systems that are flexible and include components that replicate, substitute and/or augment the natural fiber orientation of the anterior longitudinal ligament and annulus tissue. The components resist loading applied by extension and rotation of the spine, while the flexibility of the components does not subject them to the compressive loading of the spinal column segment to which it is secured.

DESCRIPTION OF THE FIGURES

Fig. 1 is an elevational view of a spinal column segment having a pair of interbody fusion devices inserted into a disc space.

Fig. 2 is a plan view of a disc space of a spinal column segment and the surrounding tissue and vasculature.

Fig. 3 is a perspective view a spinal column segment with its associated ligaments.

Figs. 4(a) and 4(b) illustrate various features of a spinal disc space.

Figs. 5(a) and 5(b) illustrate various structural properties of the annulus fibrosous.

Fig. 6 is a flexible spine stabilization system according to one embodiment secured to a spinal column segment.

Figs. 7(a) through 7(c) show various components of the system of Fig. 6.

Fig. 8 is an elevational view of another embodiment flexible spine stabilization system secured to a spinal column segment.

Fig. 8a is an enlarged detail view of a portion of the system of Fig. 8.

Fig. 9 is elevational view of yet another embodiment flexible spine stabilization system secured to a spinal column segment.

Fig. 10(a) is an elevational view of a further embodiment flexible spine stabilization system.

Fig. 10(b) is the system of Fig. 10(a) secured to a spinal column segment.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the illustrated embodiments and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the

scope of the invention is thereby intended. Any such alterations and further modifications of the invention, and any such further applications of the principles of the invention as illustrated herein are contemplated as would normally occur to one skilled in the art to which the invention relates.

5 The present invention is directed to flexible spine stabilization systems for placement on the anterior aspect of the vertebrae of a spinal column segment. It is contemplated the systems may also be placed on the antero-lateral aspect or the lateral aspect of the vertebrae. It is also contemplated that the systems can extend across one or more vertebral levels. The systems are configured to replicate, substitute and/or augment
10 the structure and function of the natural occurring fibers that protect the intervertebral disc space. It is further contemplated that the systems can be used in lieu of the placement of a rigid anterior plate across one or more disc spaces after insertion of an interbody fusion device into the disc space. It is also contemplated that the systems can be used in non-interbody fusion procedures.

15 The spine stabilization systems include a member having a first set of one or more components oriented generally in the direction of the annulus fibers, and a second set of components oriented generally in the direction of the fibers of the anterior longitudinal ligament. The use of components having such orientations provides resistance to loading applied by extension, lateral bending, and rotation of the spine. The flexibility of the
20 member does not subject it to stress shielding caused by the compressive loading of the spinal column segment to which it is secured. Thus, the spine stabilization systems of the present invention replicate, augment and/or substitute the load resistant properties capabilities of the annulus fibers and anterior longitudinal ligament.

25 Further description of flexible spinal stabilization systems is provided after the following discussion of the anatomical features of the annulus and anterior longitudinal ligament. Referring now to Fig. 3, a spinal column segment including an upper vertebra V1 and lower vertebra V2 is illustrated. The spinal column segment includes anterior longitudinal ligament AL extending along the anterior aspects of vertebra V1 and vertebra V2 and across the intervertebral disc space between vertebrae V1 and V2. The nucleus of
30 the disc space is protected by annulus fibers AF. The spinal column segment further includes posterior longitudinal ligament PL, intertransverse ligament IL, facet capsular

ligament FC, interspinous ligament ISL, supraspinous ligament SSL, and ligamentum flavum LF. The spine is designed in such a way that when the functional spinal unit is subjected to different complex force and torque vectors, the individual ligaments provide tensile resistance to external loads by developing tension. When a surgical procedure interrupts or removes a portion of these ligaments, the ability of the spinal unit to resist these complex force and torque vectors is compromised.

The anterior longitudinal ligament AL is an uni-axial structure, and is most effective in carrying loads along the direction in which the fibers run. The anterior longitudinal ligament AL has a fibrous tissue structure that arises from the anterior aspect of the basioccipital and is attached to the atlas and the anterior surfaces of all vertebrae, down to and including a part of the sacrum. It is firmly attached to the edges of the vertebral bodies, but is less firmly affixed to the annulus fibers AF. The width of the anterior longitudinal ligament AL diminishes at the level of disc and is narrower and thicker in the thoracic region of the spine. The fibers of the anterior longitudinal ligament run along the length of the spinal column in the direction of the central spinal column axis and transverse to axial plane H. The fibers of the anterior longitudinal ligament AL are much like rubber bands in that they readily resist tensile forces, but buckle when subjected to compressive forces.

Referring now to Figs. 4(a) and 4(b), further properties of the spinal disc space D will be discussed. The nucleus pulposus N of the disc space is surrounded by the annulus fibrosus AF. The annulus fibrosus AF includes a number of concentric laminated bands, designated as annulus laminates AN1, AN2, AN3, and AN4 as shown in Fig. 4(a). As shown further in Fig. 4(b), these annulus laminates AN have fibers oriented either +30 degrees or -30 degrees with respect to axial plane H of the spinal column. Stated another way, the AN fibers are oriented about +60 degrees or about -60 degrees with respect to the fibers of the anterior longitudinal ligament AL. The fibers of the adjacent annulus laminates AN are non-orthogonal with respect to axial plane H and to one another, forming a criss-cross pattern as shown by AN1 and AN2 of Fig. 2(b). When interbody fusion devices or other implants are inserted between the vertebrae, or when the disc space is access for surgical procedures, the resection, removal and other cutting required of the

annulus laminates AN and anterior longitudinal ligament AL disrupts fiber orientation and continuity.

Referring now to Figs. 5(a) and 5(b), the tensile properties and strength properties of the annulus fibrosis will now be discussed. The annulus fibers AF resist tensile forces and torque or rotational forces applied to the spinal column segment. In Fig. 5(a), the tensile stiffness of the annulus AF in different directions is shown. The stiffness of annulus fibrosus AF is highest along a direction oriented 15 degrees with respect to axial plane H. In Fig. 5(b), the strength of the annulus AF has been found to be greatest along a direction oriented 30 degree with respect to horizontal axis H extending through the disc space. It has further been found that the strength of the annulus AF is three times greater along this 30 degree axis as compared to the strength along axial plane H.

Referring now to Fig. 6, a spine stabilization system 20 is illustrated. System 20 is secured to vertebra V1 and vertebra V2 and extends across the disc space D. It is contemplated that one or more interbody fusion devices, interbody spacers, artificial discs or other implant can be inserted into disc space D in a procedure prior to attachment of system 20 to vertebrae V1 and V2. It is also contemplated that a surgical procedure can be performed in or on disc space D such as, for example, removal of discal material to repair a herniated disc. In such procedures, the excision or disruption to the annulus fibrosus AF and the anterior longitudinal ligament AL compromises the ability of these spinal structures to resist extension, torsion, and lateral bending of the spinal column. System 20 can restore this ability and can cover the entry made through the annulus fibrosis AF and anterior longitudinal ligament AL, preventing devices inserted into the disc space from backing out or protruding through the created opening.

System 20 includes diagonal components and vertical components. The diagonal components can be oriented in the range of 15 degrees to 60 degrees with respect to axial plane H when the devices are secured to the vertebrae. The vertical components extend generally perpendicular to axial plane H. Stated another way, a first set of diagonal components extends at an angle A1 in the range of +30 degrees to +75 degrees relative to the vertical components, and a second set of diagonal components extends transverse to the first set and at an angle A2 in the range of -30 degrees to -75 degrees relative to the vertical components. In another form, the first set of diagonal components extends at an

angle A1 in the range of +45 degrees to +60 degrees relative to the vertical components, and the second set of diagonal components extends transverse to the first set and at an angle A2 in the range of -45 degrees to -60 degrees relative to the vertical components. In a further form, the first set of diagonal components extends at an angle A1 of about +60 degrees relative to the vertical components, and the second set of diagonal components extends transverse to the first set and at an angle A2 of about -60 degrees relative to the vertical components.

Referring now to Figs. 7(a) through 7(c), there are shown various components of system 20. System 20 includes a member extending between the first and second vertebrae V1 and V2. The member includes a first layer 30 which has a number of vertically oriented components 34 and a number of horizontally oriented components 32. Components 32, 34 are interwoven or otherwise attached to form a grid-like or mesh pattern having a number of square apertures therethrough. The member further includes a second layer 35 as shown in Fig. 7(b) having a number of first diagonal components 36 and a number of second diagonal components 38. Diagonal components 36 and 38 are interwoven or otherwise attached to form a grid-like or mesh pattern having a number of diamond-shaped apertures. Each layer 30, 35 is flexible in compression yet inelastic or substantially inelastic to resist tensile loading.

The individual components 32, 34, 36, 38 of each layer can be made from a small diameter or cross-section wire, fiber, rod, strand or other elongated component. As shown in Fig. 7(c), first layer 30 is placed on top of second layer 35 and secured thereto via grommets 26. Other securement devices and techniques are also contemplated, including, for example, other fasteners such as rivets, clamps, cables, sutures, staples, and hooks; and chemical/thermal bonding, such as welding or adhesives. Other embodiments contemplate that layers 30, 35 are not engaged to one another, but rather simply placed on top of one another when secured to the spinal column.

A number of openings 24 are formed through the layers to accommodate fasteners 22. In the illustrated embodiment, four such openings are formed, with one opening positioned adjacent each corner. Eyelets or grommets 26 extend around each hole 24. As shown in Fig. 6, bone engaging fasteners 22 can be placed through corresponding ones of the holes 24 to secure layers 30, 35 to vertebrae V1 and V2. The corners of layers 30, 35 can be

rounded to provide gradual transitions between the vertical and horizontal edges thereof. Other embodiments contemplate one opening 24 at each vertebra, and further embodiments contemplate more than two openings 24 at each vertebra. Other embodiments also contemplate that no openings are provided, but rather the fasteners extend directly through the layers of material.

The vertically extending components 34 of first layer 30 are oriented and function in a manner similar to the longitudinal fibers of the anterior longitudinal ligament AL. Diagonal components 36, 38 of second layer 35 are non-orthogonally oriented with respect to the vertical components 34, and are oriented and function similar to annulus fibers AF. Thus, system 20 replaces, substitutes, and/or augments the function of the naturally occurring fibers of the anterior longitudinal ligament AL and the annulus fibrosis AF. The orientation of the components of system 20 are such that forces caused by extension, rotation, and lateral bending of the spinal column are resisted in a manner the same as or similar to the natural occurring anatomical structures provided to resist such forces.

Referring to Fig. 8 and 8a, there is provided a spine stabilization system 40 having a layer 46. Layer 46 includes a number of interwoven components that include at least longitudinally and diagonally oriented components. In the illustrated embodiment, there are provided first diagonal components 47, second diagonal components 48, vertical components 49, and horizontal components 45. The first and second diagonal components 47, 48 are oriented and function similar to the fibers of the annulus fibrosis AF, and the vertical components 49 are oriented and function similar to the anterior longitudinal ligament AL. Small apertures are provided through layer 46 between its components. Eyelets or grommets 44 each surround a corresponding one of the holes provided through layer 46. Bone engaging fasteners 42 extend through these holes to attach system 40 to vertebra V1 and vertebra V2.

Referring now to Fig. 9, there is shown another embodiment spine stabilization system 50. The components of system 50 are diagonally and vertically oriented to replicate the orientation of the fibers of the anterior longitudinal ligament AL and annulus fibers AF. System 50 includes a member formed by a layer 56 made from components interwoven such that there are no apertures through layer 56, providing a substantially solid wall across disc space D. Layer 56 includes a number of holes formed therethrough

surrounded by grommets or eyelets 54. Fasteners 52 extend through the holes in order to secure the flexible system 50 to vertebra V1 and V2 across the annulus fibrosis AF.

Referring now to Fig. 10(a), another embodiment spine stabilization system 60 is illustrated. System 60 includes member having a first vertical component 66 and a second vertical component 68. Vertical components 66 and 68 are interconnected by a first diagonal component 70 and a second diagonal component 72. As shown in Fig. 10(b), first diagonal component 70 extends from a right lateral side of vertebral body V2 across the sagittal plane L to a left lateral side of vertebral body V1. Second diagonal component 72 extends from the left lateral side of vertebral body V2 across the sagittal plane L to the right lateral side of vertebral body V1. The first vertical component 66 extends from a left lateral side of vertebral body V2 to the left lateral side of vertebral body V1 offset to one side of sagittal plane L. Second vertical component 68 extends from the right lateral side of vertebral body V2 to the right lateral side of vertebral body V1 offset to the other side of sagittal plane L. In each corner of system 60 there is formed a hole 64 for receiving a fastener 62 to attach system 60 to vertebrae V1 and V2.

The vertically oriented components 66, 68 are oriented to replace, substitute and/or augment the structure function of the anterior longitudinal ligament AL and resist at least extension forces applied to the spinal column segment. The diagonal components 70, 72 are non-orthogonally oriented with respect to the vertically oriented components 66, 68 and resist at least rotational and torque forces on the spinal column segment. Thus, diagonal components 70, 72 are oriented and function similar to the fibers of the annulus fibrosis AF.

The components of the flexible spinal stabilization systems can be made from one or a combination of metal material, polymeric material, ceramic material, shape memory material, and composites thereof. The components of the systems can also be coated or impregnated with anti-adhesive material that will prevent tissue and vasculature from attaching thereto. The components of the systems can be provided in multiple layers each including one or more components with the desired orientation and placed one on top of the other, or the components can be provided in a single interwoven layer that includes the desired component orientation.

In one specific embodiment, the components are made from metal wire mesh of suitable tensile strength and which is not subject to substantial creep deformation or in vitro degradation. It is contemplated that the wire can be made from stainless steel, cobalt-chrome alloy, titanium, titanium alloy, or nickel-titanium, among others.

5 In another specific embodiment, the components are made from a soft fiber material. Soft fiber material can include polymeric material, such as SPECTRA fiber, nylon, carbon fiber and polyethylene, among others. Examples of suitable metal polymers include DACRON and GORE-TEX. One advantage provided by a soft fiber design is that the risk of tissue and vascular injury is further mitigated by reducing the abrasive qualities
10 of the component material. A further advantage is that the components fibers can be radiolucent, allowing radiographic imaging for assessment and monitoring of the disc space and any implant, fusion devices, or artificial disc inserted therein. Another advantage is that some polymeric materials, such as spectra fiber, can be stronger than metals and less susceptible to fatigue or creep.

15 While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that the preferred embodiments have been shown and described, and that all changes and modifications that come within the spirit of the invention are desired to be protected.

What is claimed is:

1. A stabilization system for a spinal column segment with an anterior longitudinal ligament having a first fiber orientation extending in the direction of a central spinal column axis, the spinal column segment having annulus tissue with a second fiber orientation extending at an acute angle to the first fiber orientation and a third fiber orientation extending at an acute angle to the first fiber orientation and transverse to the second fiber orientation, the system comprising:

a flexible member attachable to the bodies of at least first and second vertebrae of the spinal column segment, said member including at least one first component extending in the direction of the first fiber orientation, at least one second component extending generally in a direction corresponding to the second fiber orientation, and at least one third component extending generally in a direction corresponding to the third fiber orientation.

2. The system of claim 1, wherein said at least one first component includes a number of first components forming a first mesh layer with a number of fourth components extending transverse to said number of first components.

3. The system of claim 2, wherein said at least one second component includes a number of second components and said at least one third component includes a number of third components, said number of second and third components forming a second mesh layer.

4. The system of claim 3, wherein said first mesh layer and said second mesh are place one on top of the other for attachment to the bodies of the first and second vertebrae.

5. The system of claim 3, wherein said first mesh layer is interwoven with said second mesh layer.

6. The system of claim 1, further comprising fasteners for attaching the member to each of the first and second vertebrae.

7. The system of claim 1, wherein said at least one first component, said at least one second component, and said at least one third component are inelastic.

5 8. The system of claim 1, wherein said at least one first component, said at least one second component, and said at least one third component include a tissue anti-adhesion material.

10 9. The system of claim 1, wherein said member defines a plurality of openings therethrough.

15 10. The system of claim 1, wherein said at least one second component forms a first angle in the range of +30 to +75 degrees with said at least one first component and said at least one third component forms a second angle in the range of -30 to -75 degrees with said at least one first component.

11. The system of claim 10, wherein said first angle is in the range of +45 to +60 degrees and said second angle is in the range of -45 to -60 degrees.

20 12. The system of claim 10, wherein said first angle is about +60 degrees and said second angle is about -60 degrees.

25 13. The system of claim 1, wherein said member is attachable to an anterior face of said first and second vertebrae.

14. The system of claim 1, further comprising at least one spinal fusion implant between the first and second vertebrae.

30 15. A stabilization system for a spinal column segment with an anterior longitudinal ligament having a first fiber orientation extending in the direction of a central spinal column axis, the spinal column segment having annulus tissue with a second fiber

orientation extending at an acute angle to the first fiber orientation and a third fiber orientation extending at an acute angle to the first fiber orientation and transverse to the second fiber orientation, the system comprising:

5 a flexible member attachable to the bodies of first and second vertebrae of the spinal column segment, said member including at least one layer formed by a number of first components extending in the direction of the first fiber orientation, a number of second components extending generally in a direction corresponding to the second fiber orientation, and a number of third components extending generally in a direction corresponding to the third fiber orientation.

10 16. The system of claim 15, wherein said layer further comprises a number of fourth components extending transverse to said number of first components.

15 17. The system of claim 15, wherein said first components, said second components and said third components are interwoven with one another.

18. The system of claim 15, further comprising fasteners for securing the member to each of the first and second vertebrae.

20 19. The system of claim 15, wherein said first components, said second components, and said third components are inelastic.

25 20. The system of claim 15, wherein said member defines a plurality of apertures therethrough.

21. The system of claim 15, wherein said second components form a first angle in the range of +30 to +75 degrees with said first components and said third components form a second angle in the range of -30 to -75 degrees with said first components.

30 22. The system of claim 15, wherein said first angle is in the range of +45 to +60 degrees and said second angle is in the range of -45 to -60 degrees.

23. The system of claim 15, wherein said first angle is about +60 degrees and said second angle is about -60 degrees.

5 24. The system of claim 15, wherein said at least one layer is a wire mesh made from a material selected from the group consisting of: stainless steel, cobalt-chrome alloy, titanium, titanium alloy, nickel-titanium, and shape memory metal alloy.

10 25. The system of claim 15, wherein said at least one layer is a mesh made from a material selected from the group consisting of: polymers and metal polymers.

15 26. A stabilization system for a spinal column segment with an anterior longitudinal ligament having a first fiber orientation extending in the direction of a central spinal column axis, the spinal column segment having annulus tissue with a second fiber orientation extending at an acute angle to the first fiber orientation and a third fiber orientation extending at an acute angle to the first fiber orientation and transverse to the second fiber orientation, the system comprising:

a flexible member attachable to the bodies of first and second vertebrae of the spinal column segment, said member including:

20 at least one first layer formed by a number of first components extending in the direction of the first fiber orientation; and

at least one second layer formed by a number of second components extending generally in a direction corresponding to the second fiber orientation, and a number of third components extending generally in a direction corresponding to the third fiber orientation.

25 27. The system of claim 26, wherein said first layer and said second layer are secured to one another.

30 28. The system of claim 26, wherein said at least one first layer further includes a number of fourth components extending transversely to said number of first components.

29. The system of claim 26, wherein said member has a number of holes formed through said first and second layers sized to receive fasteners for attaching said member to the first and second vertebrae.

5 30. The system of claim 29, wherein each of said holes includes a grommet extending therearound.

31. The system of claim 30, wherein said grommets secure said first layer to said second layer.

10 32. The system of claim 26, wherein said member defines a plurality of apertures therethrough.

15 33. The system of claim 26, wherein said at least one second component forms a first angle in the range of +30 to +75 degrees with said at least one first component and said at least one third component forms a second angle in the range of -30 to -75 degrees with said at least one first component.

20 34. The system of claim 33, wherein said first angle is in the range of +45 to +60 degrees and said second angle is in the range of -45 to -60 degrees.

35. The system of claim 33, wherein said first angle is about +60 degrees and said second angle is about -60 degrees.

25 36. The system of claim 26, wherein each of said first layer and said second layer is a wire mesh made from a material selected from the group consisting essentially of: stainless steel, cobalt-chrome alloy, titanium, titanium alloy, nickel-titanium, and shape memory metal alloy.

30 37. A method for stabilizing a portion of a spinal column including an anterior longitudinal ligament and an annulus having a first portion of fibers oriented in a first

direction transverse to the anterior longitudinal ligament and a second portion of fibers oriented in a second direction transverse to the anterior longitudinal ligament and transverse to the first portion of fibers, the method comprising:

5 providing at least one first component oriented in the direction of the anterior longitudinal ligament;

providing at least one second component oriented in the direction of the first portion of the annulus fibers;

providing at least one third component oriented in the direction of the second portion of the annulus fibers; and

10 securing the at least one first component, the at least one second component and the at least one third component to first and second vertebrae of the spinal column.

38. The method of claim 37, further comprising applying a tissue non-adhesive coating to the at least one first component, the at least one second component and the at least one
15 third component.

39. The method of claim 37, wherein the at least one first component, the at least one second component and the at least one third component are interwoven in a mesh layer.

20 40. The method of claim 37, further comprising providing at least one fourth component oriented transversely to the at least one first component.

41. The method of claim 40, further comprising:
providing the at least one first component and the at least one fourth component in a first
25 mesh layer;
providing the at least one second component and the at least one third component in a second mesh layer; and
placing the first mesh layer and the second mesh layer one on top of the other.

42. The method of claim 37, further comprising inserting an implant between the first and second vertebrae before securing the at least one first component, the at least one second component and the at least one third component to the first and second vertebrae.

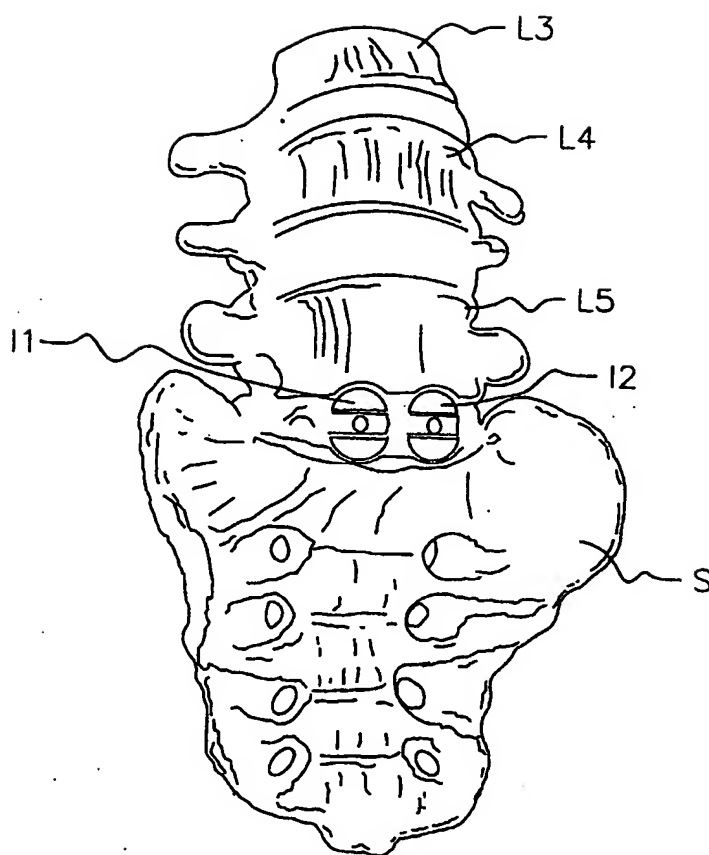


Fig. 1

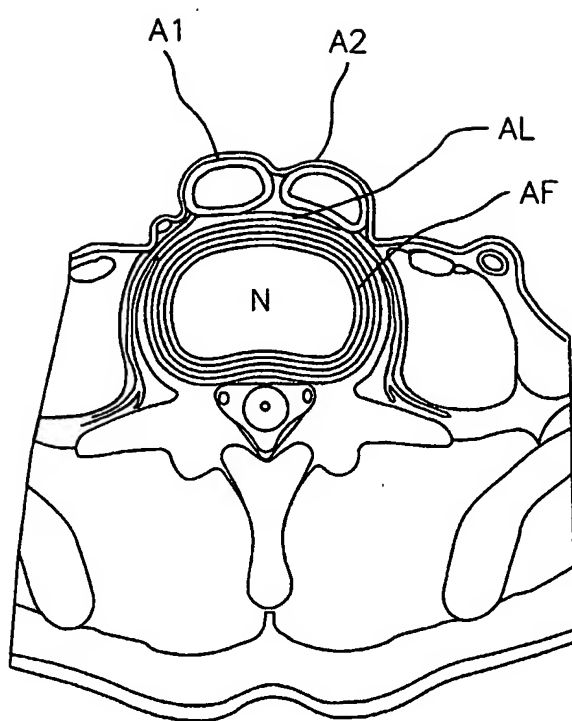


Fig. 2

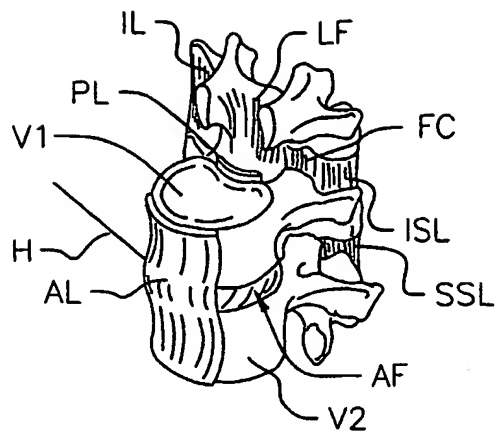


Fig. 3

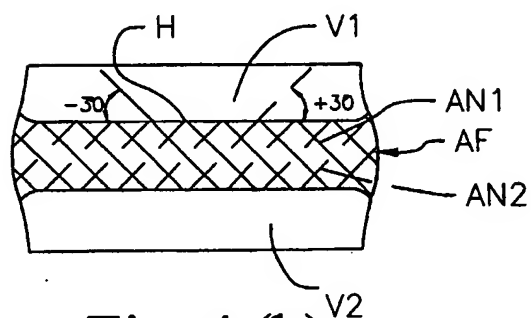


Fig. 4 (b)

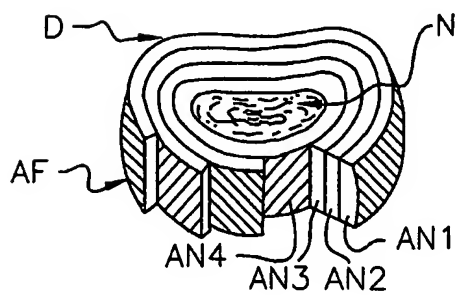


Fig. 4 (a)

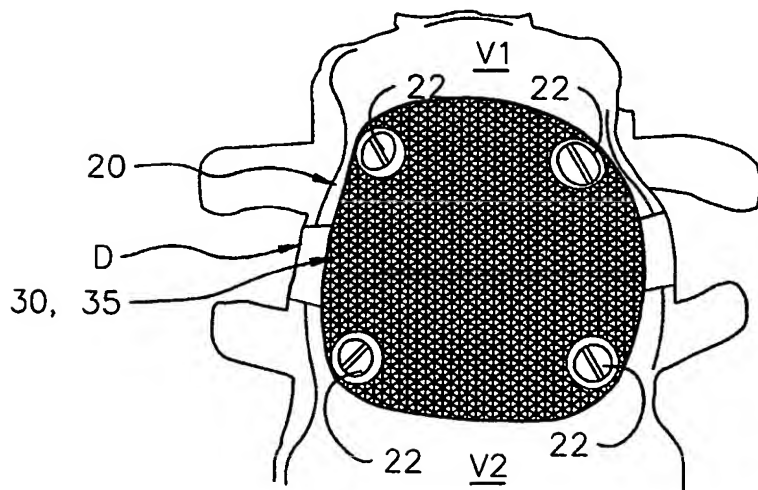
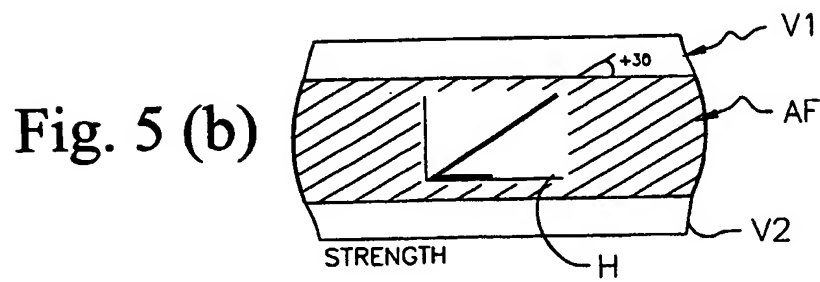
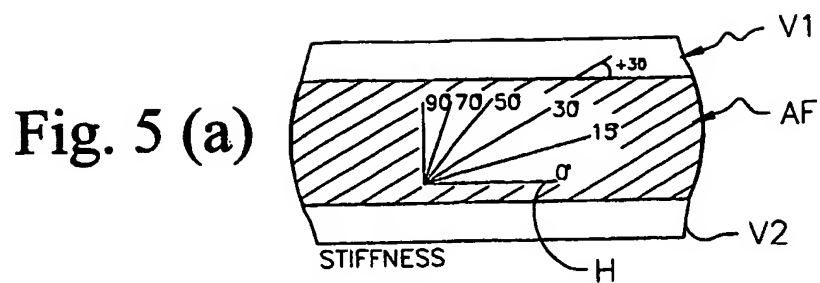
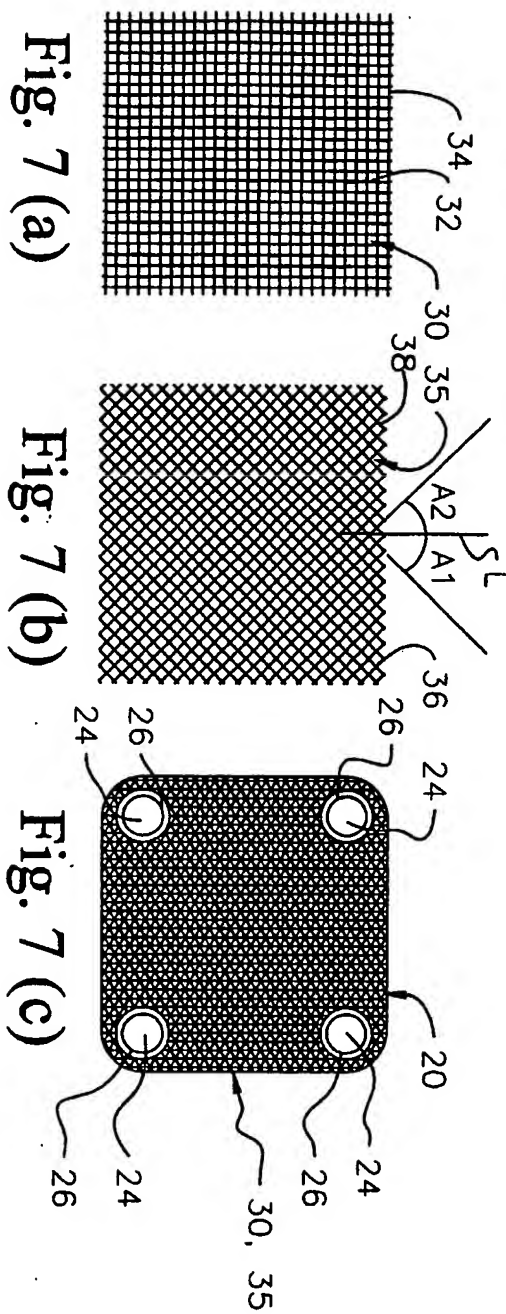


Fig. 6



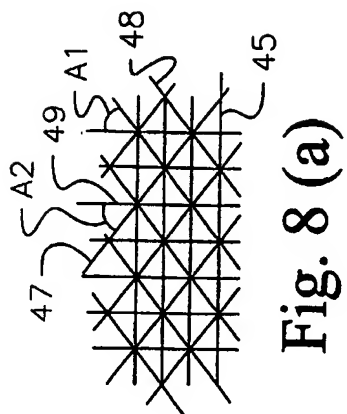


Fig. 8 (a)

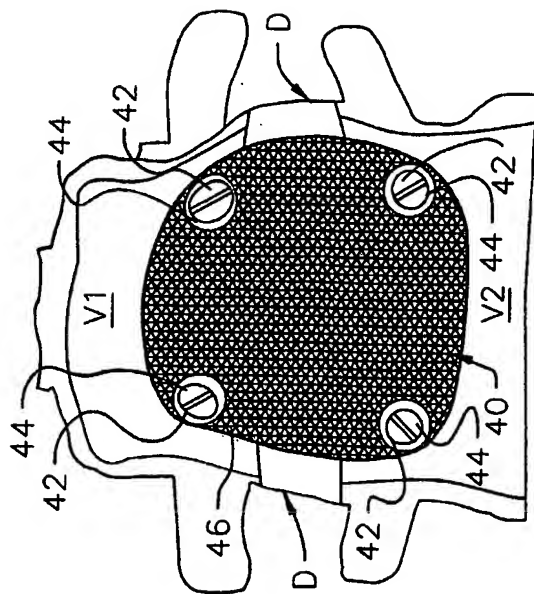


Fig. 8

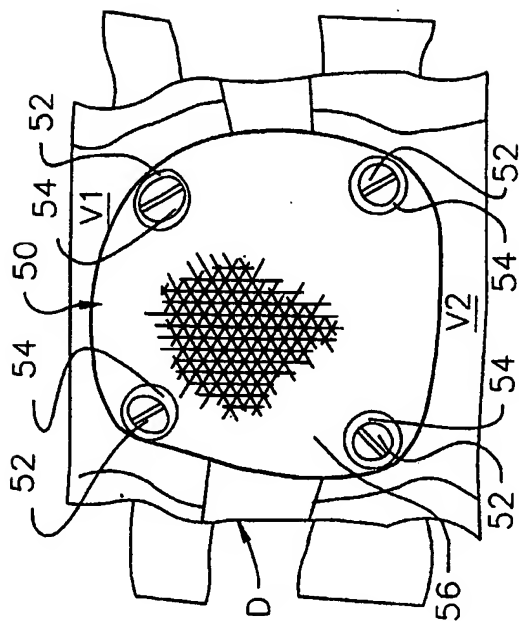


Fig. 9

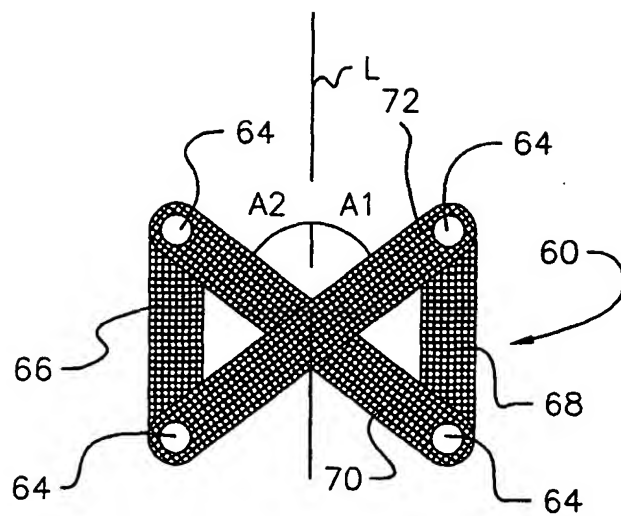


Fig. 10 (a)

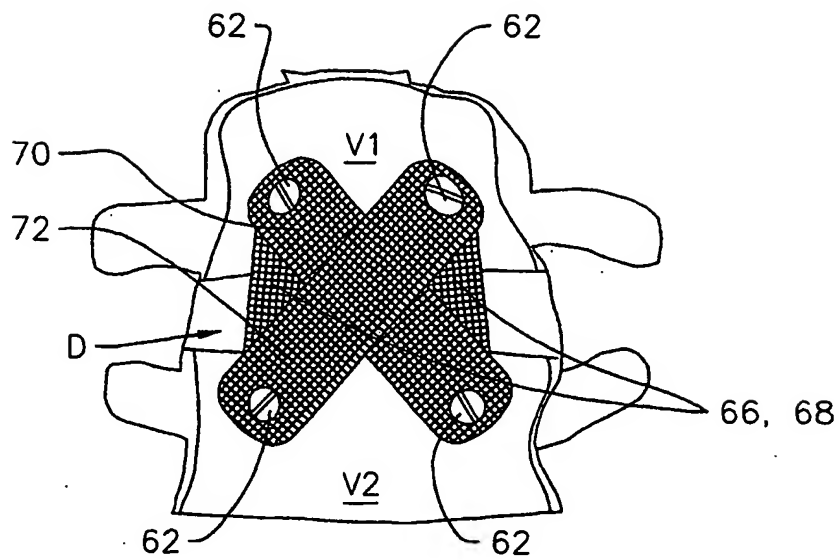


Fig. 10 (b)

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